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CURRENT MARKET ECONOMICS OF THE STRONTIUM MINERALS

Submitted by
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and
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To
The Honourable Joel R. Matheson, Q.C.
Minister
Department of Mines and Energy
of
The Province of Nova Scotia

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METALS ECONOMICS GROUP

FOREWORD

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The views expressed are those of the authors, and do not necessarily represent the views of the Nova Scotia Government.

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INTRODUCTION AND METHODOLOGY

The purpose of this study is to provide a "quick and dirty" analysis of the market economics of celestite and the strontium compounds produced from it, in order to aid the government of Nova Scotia in negotiating with potential developers of the Enon deposit. We have also included a number of observations, that we have developed in the course of the study, on the feasibility of the Enon project .

We began the study with a thorough review of all market-related publications on the strontium minerals in English, French, and German. In the course of doing this, we found that the best single source of information was the U. S. Bureau of Mines, and engaged in numerous discussions with them. We chose to concentrate on the U. S. market as it was the obvious outlet for a Canadian producer and good information could be developed within the time and budget restraints of this study.

We spoke directly with all the major celestite and strontium compound producers in the United States, as well as with the U.S. and Canadian governments and with market participants in Canada and Spain. Given the specialized and often secretive nature of the industry, we found it necessary to have several conversations with most of our informants as we progressively uncovered different layers of the market puzzle.

For consistency, prices and production figures have been reported in metric tonnes in the text. Some U.S. Bureau of Mines tables have been given as originally reported, in short tons.

EXECUTIVE SUMMARY

The markets for celestite and the strontium compounds produced from it are currently tight, and there is a good deal of interest in new sources of supply. If it could be competitive, Canadian supply would be particularly welcome because of the geopolitical distribution of current celestite production.

Celestite containing over 85% strontium sulphate is currently produced in thirteen countries, with western world production concentrated in the hands of four small independent companies in Mexico, Spain, Turkey, and England. There is no current production in Canada or the United States.

The major market for celestite is in the manufacture of strontium chemicals (hereinafter referred to as "compounds," following industry usage). There is a very limited market for celestite or strontium sulphate in raw forms. Strontium carbonate, used primarily in colour television picture tube face glass and to a lesser extent in ferrite magnets, commands 85% of the market for strontium compounds. Strontium nitrate, used primarily in pyrotechnics, takes 10% of the market. A number of strontium compounds with a variety of uses account for the remaining 5%.

The United States and Japan have in recent years accounted for 45% and 30% respectively of strontium compound consumption, with Europe taking about 20%. The Canadian market is very small.

The current market for celestite worldwide is on the order of 110,000 tonnes. The main strontium end uses are showing good growth, and most celestite and compound producers worldwide seem to be operating at or near capacity. There is a shortage in the United States of strontium compounds and there are

concerns over the adequate future availability of celestite, which is almost entirely imported from Mexico. Current U.S. delivered prices for celestite are about $140 per tonne, and for strontium carbonate about $670 per tonne.

Demand is expected to continue to show reasonable to strong growth in the major strontium compound end uses; strontium has decisively proved its advantage over barium, its chief competitor. U.S. concerns over celestite supply are exacerbated by the fact that the Mexican company that is the major supplier of celestite for strontium compound manufacture is now itself beginning to produce strontium compounds, in competition with its U.S. customer. The U.S. producer, Chemical Products Corporation, and its customers, such as RCA and Corning Glass, all express a great interest in developing new sources of material. A Canadian source such as Enon is particularly attractive in light of Canada's proximity, stability, and close relationship with the United States. As much of the celestite imported for processing in the other industrialized country markets comes from less developed areas, a Canadian source might also prove a politically attractive alternative supplier to Europe and Japan as well.

As there is currently limited consumption of celestite in Canada, development of the mine to exclusively service a Canadian market would likely entail a very small operation.

New celestite production is being planned in Mexico, expansions are being completed elsewhere, and no doubt several other potential new producers are being evaluated. The competitive advantage of the Enon deposit lies largely in its location in an area of relative political and financial stability and its proximity to the U.S. market. An experienced nucleus of skilled laborers is available in Cape Breton. On the other hand, the deposit has high production costs relative to its third-world competitors due to low ore grade, complexity of mining, and high labor costs. Feasibility would be particularly sensitive to transportation costs. However,

it might be possible for a developer of the Enon deposit to press its geographical advantage for a small premium or for longer-term, fixed price contracts.

However, the feasibility of strontium compound production at Enon, which would be less sensitive to labor and freight costs, would be adversely affected by the severe competition likely to be encountered from both established and new producers.

OCCURRENCES OF CELESTITE

Celestite, the commercial ore mineral of strontium, is a member of the alkaline earths and is fairly widely distributed throughout the world, primarily in sedimentary deposits. Strontium occurs in celestite as strontium sulphate ($SrSO_4$). Another strontium mineral, strontianite ($SrCO_3$), was used in the production of strontium nitrates before this century but known deposits are rare and small. Strontium also occurs as a minor element in Scandinavian apatites, although it has yet to be commercially exploited from these deposits.

Celestite occurs in massive, crystalline, bladed, fibrous, or earthy forms. It is frequently found in conjunction with other minerals such as gypsum, rock salt, galena, and sphalerite, although byproducts or coproducts are rarely recovered in commercial quantities. The chemical nature of celestite is close to that of anhydrite and barite, and strontium, barium and calcium chemicals compete in a number of usages. Celestite has a density of 3.95 to 3.97 and a hardness of about 3.5. It is insoluble in acids and is an efficient absorber of x-rays.

Despite the widespread occurrence of celestite, only a few deposits are commercially workable. Many are plagued by their celestite being economically inseparable from calcite or gypsum, while others have unacceptably high levels of barium or other impurities.

Western world production of celestite is currently dominated by four small independent companies located in Mexico, Spain, Turkey, and England. With the exception of the largest Mexican producer, an underground vein operation, all current celestite operations are surface mines. All yield a grade of more than 90%

strontium sulphate by simple means of hand sorting, washing, or gravity separation.

The list of current celestite producers also includes Pakistan, Italy, Algeria, Argentina, China, the U.S.S.R., Cyprus, Poland, and Madagascar. The United States, Tunisia, and Morocco all produced minor amounts in the post World War II period; France, Australia, and West Germany produced small amounts prior to the 1940s; and Canada was a major producer in the late 1960s and early 1970s. None of these countries are currently producing. Potentially economic deposits have been reported in Malawi, Qatar, and India in recent years.

In eastern Canada, in addition to the Nova Scotia deposits, celestite occurrences have been investigated in Ontario, New Brunswick, and Newfoundland. One of the Ontario deposits examined in the 1930s reported indicated grades of 93% $SrSO_4$, although as far as we could ascertain, reserves were not further delineated. In the Newfoundland and New Brunswick occurrences, celestite is mixed with barite, making economic recovery difficult.

The United States has celestite deposits in Texas, California, Arizona, and Washington, with total reserves estimated at two million tons, grading 85%. All are currently uneconomic.

THE USES OF CELESTITE AND THE STRONTIUM COMPOUNDS

The major market for celestite is in the manufacture of strontium chemicals or compounds. There are some limited markets for celestite or its major component, strontium sulphate, in their raw forms. Celestite has been occasionally used directly as a paint filler, as a replacement for barium in drilling muds, as a construction filler for sound deadening, and as a filler in rubber and plastics used in x-ray work.

There are a variety of strontium compounds produced from strontium sulphate (for details on the production process see the Appendix). The most significant is strontium carbonate, which finds its primary use in colour television picture-tube glass and commands 85% of the market for strontium compounds. Next is strontium nitrate, used primarily in pyrotechnics, which takes 10% of the market. A host of other strontium compounds with a variety of uses account for the remaining 5%.

In recent years, by geographical area, the United States and Japan have accounted for about 45% and 30% respectively of celestite demand, with Europe taking about 20% and other countries 5%.

Strontium carbonate

The major uses of strontium carbonate are in the manufacture of colour television picture-tube face glass and ceramic ferrite magnets. Strontium carbonate

is also used in zinc refining, in various chemical purification processes, and in ceramic-ware manufacture.

Colour Television Picture-Tube Glass. Strontium carbonate is used in the production of colour television picture tubes to shield against the emission of harmful x-rays and to provide a brighter picture. Barium is used for these purposes in European colour television sets, which use lower voltages and thus create less harmful x-rays than those manufactured in the United States or Japan. Tubes manufactured in the United States and Japan typically contain 5% to 7% strontium oxide (as well as 3% to 4% barium oxide) in their face glass.

The colour television picture-tube market accounts for about 65% of the U.S. consumption and 60% of worldwide consumption of all strontium compounds.

Ceramic Ferrite Magnets. Ferrite magnets are currently used in the production of fractional horsepower motors for stereos, windshield wiper motors, electric window motors, heater motor fans, loudspeakers, and various home appliances.

Ceramic ferrite magnets were first patented in Japan in the 1930s, although commercial acceptance did not come until two decades later. Ceramic ferrite magnets are produced by sintering strontium carbonate in pelletized form with iron oxide. They have the advantage of being smaller and more efficient than the previously popular lead-barium magnets. The manufacturing technique is also cheaper and simpler than that for aluminum, nickel, or cobalt magnets.

Magnet production represents between 5% and 10% of the U.S. market for strontium compounds, 35% of the Japanese consumption, and 20% of the world total.

Zinc Refining. In the 1950s, a process was developed using strontium carbonate to produce Special High Grade zinc. Approximately seven pounds of

strontium carbonate are used per tonne of zinc to remove lead from the cathode zinc prior to electrolysis.

This use accounts for about 4% of total U.S. consumption of strontium compounds and somewhat less of Japanese and world consumption.

Chemical Purification. Strontium carbonate is used in a number of chemical purification processes, primarily to remove SO_4 ions. These processes include purification of Nacl brines in a chloralkali electrolysis, purification of phosphoric acid, and purification of bauxite-lixivation lye in the Bayer process. Strontium carbonate is also sometimes used in the extraction of citric acid from fruits.

These uses account for about 2% of strontium compound consumption worldwide.

Ceramics. Strontium carbonate is used in the ceramics industry to increase the firing range in pottery and both improve the glaze and increase scratch resistance in porcelain and china.

This industry accounts for about 1% of total strontium compound consumption.

The ceramic, chemical, and ferrite magnet industries tend to prefer finer carbonates with high reactivity, while the glass industry uses coarser material.

Strontium Nitrate

Strontium nitrate is used in the production of flares, fireworks, and tracer bullets. The nitrate, along with small amounts of other strontium compounds, imparts a brilliant red colour to the flame.

Fifteen percent of the U.S. demand for compounds is consumed for pyrotechnics. In Japan only 2% goes to these uses. Strontium nitrate compounds account for 10% of world consumption of strontium compounds.

Other Strontium Compounds

The use of all other strontium compounds together makes up only 2% of total world consumption. In some cases the total market for the end product is small. In others, strontium compounds are subject to strong competition, while in yet others, only a small amount of compound is required.

Strontium chromate, which is produced from strontium nitrate, is used as a yellow pigment. It is commonly used in marine paints for its qualities as a corrosion inhibitor. It is easy to grind and has good fastness, although it has a low tint strength and is susceptible to alkali/acid attack.

Strontium sulphide is used as a phosphorescent pigment in some luminescent paints.

Both strontium sulphide and strontium chromate have the advantage in paint usages of being nontoxic, nonflammable, not gelling to acid media, and dilutable in water.

Strontium metal is used to extract gases from electronic tubes. It is also used as a modifying agent in the production of hypoeutectic aluminum-silicon casting alloys. A lead-strontium product is used in maintenance-free storage batteries.$

Strontium titanate is used in the production of very small capacitors and self-regulating heating elements. It is also used in frits and glazes in ceramics.

Strontium hexaferrite is produced from strontium carbonate as an intermediate step in the production of most strontium-based ferrite magnets.

Strontium phosphate is used in fluorescent lights.

Strontium hydroxide is used in the manufacture of some paints and oils as a drying agent. Its original use, now confined to East Germany, was in sugar beet refining.

Strontium chloride is an ingredient in toothpaste for sensitive teeth.

Strontium bromide is used as a sedative.

Strontium oxalate and **strontium peroxide** are used, along with strontium nitrate, in pyrotechnics.

TABLE 1

Estimated Current End Uses of Strontium Compounds in the United States

Colour television tubes	65%
Pyrotechnics	15%
Ferrite magnets	7%
Pigments and fillers	4%
Zinc refining	4%
Chemical purifications	2%
Ceramics	1%
Others	2%

Sources: Various

A BRIEF HISTORY OF THE MARKETS

The first recorded production of a strontium mineral was of strontianite in Germany, in the late 1700s. Strontium hydroxide was used early on for the refining of beet sugar, and strontium nitrate (and related compounds) were used for the manufacture of flares and fireworks. Regular production of celestite began in England in the 1880s. While England consumed some celestite domestically, the bulk of early English production was exported to Germany.

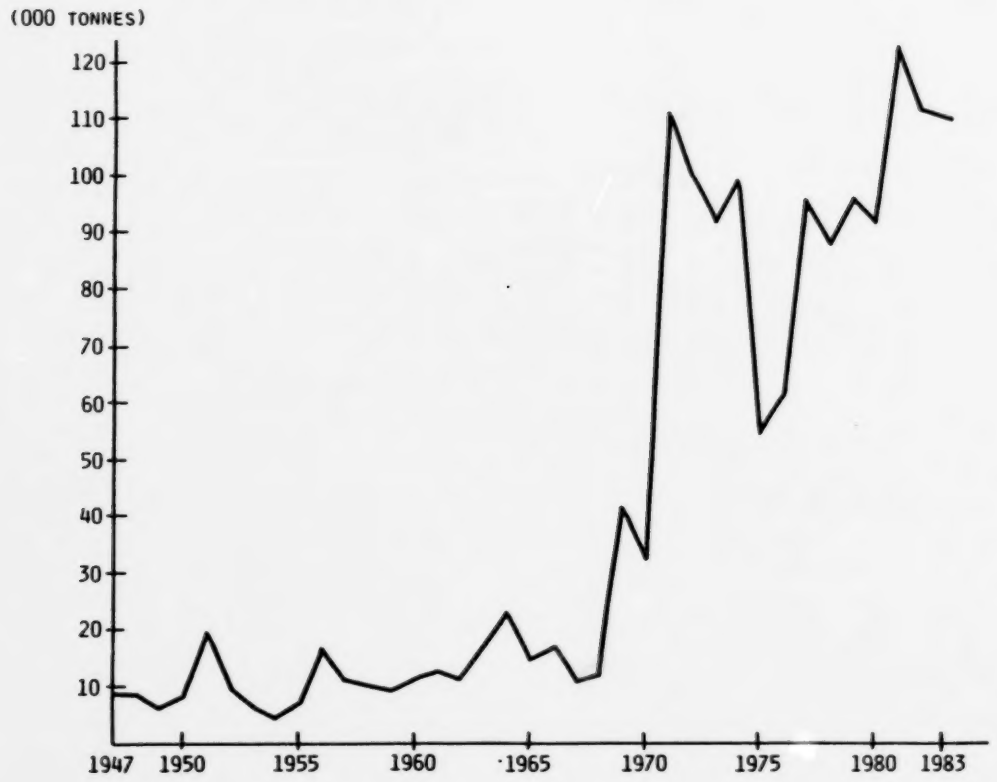
By 1915 strontium hydroxide was replaced in the sugar refining process by barium silicate. However, growing usage in pyrotechnics and ceramics justified continued celestite production.

In the 1920s Germany restarted minor celestite production (its highest output in one year was 900 tonnes), but it continued to import the major portion of its supply from England. The last known German production was in 1937. France also produced during the 1920s, with its last reported output in 1933.

In the mid-1930s, English celestite production was spurred by the newly developed use of celestite in oil drilling muds. The celestite was finely ground and used as a replacement for barite, which had become subject to a high royalty in the United States. Barite resumed its dominance in oil-drilling uses in the 1940s.

Another dramatic increase in celestite production came about during World War II, when strontium compounds came into demand for tracer bullet and flare manufacture. Spain, Mexico, and the United States entered the marketplace to meet the new demand.

FIGURE 1
WORLD CELESTITE PRODUCTION 1947-1983



Spain and the United States ceased production in 1946-47 (the United States had sporadic production again between 1952 and 1959), and total world output of celestite dropped below the prewar level. However, England resumed its celestite operations the following year while Mexico continued its small output. The great majority of celestite continued to be used in pyrotechnics. There was a slight upswing in demand with the commercialization of ceramic ferrite magnets in Japan in the 1960s, and with U.S. government stockpile purchases. Production ranged between 4,000 and 22,000 tonnes of celestite yearly, with brief violent fluctuations through 1968.

World celestite production more than tripled in 1969 to 40,000 tonnes. This was in response to the heightened demand resulting from the new use of strontium carbonate in the manufacture of colour television picture tubes, underscored by Japan's entry into the colour television market. England, the leading producer for more than eighty years, raised its output by more than 60% to 11,700 tonnes that year, while Mexico increased its output from a modest 3,500 tonnes to 18,000 tonnes. The increased demand also prompted the return of Spain as a celestite producer. Major new production started up in Canada at this time and small operations began in Iran and Algeria.

Mexico's ability to produce high-grade, low-cost celestite and its proximity to the world's largest consumer, the United States, allowed it eventually to become the world's dominant producer, replacing England (although for several years in the early 1970s, Canada held the premier position).

TABLE 2

World Production of Celestite 1947-1983
(000 tonnes)

	Mexico	Spain	UK	Turkey	Iran	Algeria	Italy	Argentina	Pakistan	Canada
1947	3.5	--	5.1	--	--	--	--	--	--	--
1948	1.0	--	7.5	--	--	--	--	--	--	--
1949	1.0	--	4.9	--	--	--	--	--	--	--
1950	1.8	--	6.9	--	--	--	--	--	--	--
1951	1.8	--	16.6	--	--	--	--	--	0.1	--
1952	1.1	--	8.2	--	--	--	0.1	--	0.4	--
1953	2.2	--	3.0	--	--	--	--	--	0.8	--
1954	1.7	--	2.1	--	--	--	--	--	9,3	--
1955	1.9	--	4.9	--	--	--	0.1	--	0.4	--
1956	2.2	--	9.3	--	--	--	0.2	0.4	0.3	--
1957	1.9	--	7.0	--	--	--	1.1	--	0.9	--
1958	2.2	--	5.7	--	--	--	0.6	0.2	0.5	--
1959	2.3	--	6.1	--	--	--	0.3	--	0.7	--
1960	2.7	--	6.7	--	--	--	0.8	--	0.4	--
1961	2.5	--	8.8	--	--	--	1.0	--	0.4	--
1962	4.3	--	6.6	--	--	--	0.6	--	0.3	--
1963	6.2	--	9.1	--	--	--	0.6	--	0.4	--
1964	4.9	--	17.3	--	--	--	0.5	--	0.3	--
1965	3.1	--	9.7	--	--	--	0.6	0.6	0.4	--
1966	5.7	--	9.5	--	--	--	0.6	0.4	0.5	--
1967	2.5	--	6.8	--	--	--	0.7	0.1	0.4	--
1968	3.4	--	7.9	--	--	--	0.8	0.1	0.6	--
1969	18.0	3.6	11.7	--	--	--	0.9	--	0.8	6.0
1970	12.0	--	9.5	--	--	--	0.8	0.1	0.3	10.0
1971	35.0	8.5	9.7	--	0.3	0.4	0.8	2.0	0.4	54.0
1972	24.4	8.0	4.4	--	0.3	1.9	0.7	1.0	0.3	59.0
1973	18.3	8.0	4.3	--	0.3	1.9	0.7	1.0	--	59.0
1974	29.5	8.5	2.4	4.0	0.3	1.9	0.7	0.5	6.4	55.0
1975	15.9	9.0	3.2	4.0	--	0.8	0.7	0.6	--	25.0
1976	27.3	9.0	3.4	6.3	5.4	0.7	0.7	2.0	0.4	20.0
1977	45.5	11.0	5.1	16.6	10.0	6.5	0.7	0.8	0.6	--
1978	33.2	14.0	4.3	14.5	15.0	5.1	0.3	1.0	0.2	--
1979	39.5	18.0	6.1	18.0	8.8	5.8	1.7	0.1	0.7	--
1980	40.7	19.0	6.7	16.0	5.5	3.0	1.0	0.3	0.2	--
1981	41.4	36.0	14.5	15.0	5.0	3.0	6.7	0.3	0.3	--
1982	31.7	35.0	18.0	15.0	4.5	3.0	3.2	0.8	0.3	--
1983	30.0	35.0	18.0	15.0	5.0	3.0	3.0	0.8	0.3	--
TOTAL to 1983	**502.3**	**222.6**	**297.6**	**116.4**	**60.4**	**37.0**	**31.1**	**13.1**	**13.6**	**288.0**

It should be noted that annual figures for Turkey, Iran, Algeria, Italy, Argentina, and Pakistan are the result of sporadic information and may show averaging rather than consistent production.

Source: U.S. Bureau of Mines

World production of celestite reached a peak of 111,000 tonnes in 1972 while the market for strontium compounds became oversupplied. In that same year, Sherwin Williams and Foote Mineral Company both ceased manufacturing strontium carbonate in the United States. DuPont stopped producing strontium nitrate in 1975, leaving FMC Corporation the only U.S. nitrate manufacturer.

In 1974, the U.S. government released celestite from its stockpile into the market. In 1976, slow growth in demand on top of several years of technical problems and losses helped bring about the closure of Canada's only producer, Kaiser's strontium compounds operation in Nova Scotia. Mexico increased its production of celestite and from 1977 to the present has supplied the overwhelming majority of celestite consumed in the United States.

Spain increased its production significantly in 1981 in order to meet further Japanese supply requirements. Japan had previously been supplied by Turkey and Iran, as well as Spain, but trade negotiation problems with Turkey, and revolutions and the concomitant unreliability of supply from Iran, led Japan to invite Spain to increase production to meet its total demand. (Turkey has recently begun shipping to Japan again.)

In 1984, FMC Corporation closed its strontium carbonate and nitrate plant in California, leaving Chemical Products Corporation (CPC) of Cartersville, Georgia the only major celestite consumer in the United States. FMC's closure was attributable to high production costs and an uncompetitive freight cost from California to its main markets in the central and eastern United States. CPC has expanded to fill the gap. Nevertheless, with good growth in strontium usage, CPC still finds itself unable to meet U.S. demand and has had its customers on quotas since early 1984.

Most celestite producers worldwide are currently operating at or near capacity.

TABLE 3

World Celestite Trade Flows: 1983

Source	Destination	Est. Shipment (tonnes)
Spain	Japan	22,000
	West Germany	9,000
	France	4,000
Mexico	United States	30,000
Iran	U.S.S.R.	5,000
Turkey	West Germany	10,000
	U.S.S.R.	5,000
United Kingdom	Domestic	18,000
Algeria	France	3,000
Italy	Domestic	3,000
Argentina	Europe	800
Pakistan	Europe	300

Source: Various

Prices of Celestite and the Strontium Compounds

The prices for celestite and strontium compounds are negotiated directly between producer and consumer. As the strontium market is small and competitive, accurate buying prices for celestite are difficult to ascertain from the consumers. There is currently only one consumer -- Chemical Products Corporation -- comprising the U.S. market.

Imported celestite prices are published by the U.S. Bureau of Mines for U.S. transactions, and by both the London-based *Mining Journal* and *Industrial Minerals*

Magazine for United Kingdom sales. Strontium carbonate prices are quoted in the *Chemical Marketing Reporter.*

Compilations of U. S. Bureau of Mines figures, which represent prices at the seller's point of shipment, are published below. If the U.S. Bureau of Mines' prices are to be believed (they are the best available, but the Bureau believes, they may understate actual transactions in come cases), they show that celestite values at the point of origin just recently recovered the price levels seen in the early 1960s in constant dollar terms, despite a steady growth in nominal dollar terms.

TABLE 4

Average Values of U.S. Imports of Celestite
(US$ per tonne at point of shipment)

	Actual	Based on Constant 1983 U.S. Dollars
1963	23.1	82.6
1964	25.4	81.6
1965	25.4	80.4
1966	23.1	77.1
1967	23.1	62.8
1968	24.2	62.8
1969	23.1	57.3
1970	24.2	57.3
1971	27.6	59.5
1972	29.8	64.0
1973	26.8	54.0
1974	32.0	59.5
1975	42.0	71.6
1976	45.9	75.0
1977	49.1	76.0
1978	50.3	72.7
1979	58.5	77.1
1980	59.7	71.6
1981	70.5	78.3
1982	68.3	71.6
1983	81.6	81.6

Source: U.S. Bureau of Mines

There is no standard or "producer" price for celestite. The value varies as a function of grade, impurities, and tonnages purchased. As some of the major celestite producers are located in countries with very low labor costs, they may have substantial room to compete with each other. On the other hand, transportation takes a significant percentage out of export sales.

One conclusion that could be drawn from studying Table 2 and Table 4, detailing historical world production, is that celestite prices do not seem to show much elasticity in relation to supply. It would seem to us that in this small, concentrated market new supply has been drawn out primarily by increments in demand, thus allowing for a steady increase in prices.

The United States has usually found Mexican celestite to be the cheapest source, although imports from Spain and Canada have occasionally been purchased for less. The higher price of celestite imported from England resulted in its eventual replacement by the Mexican product. For instance, in 1977 the price of Mexican celestite was $49 per tonne, while English material was over $60 per tonne. On the other hand, in 1979 Canada apparently sold some celestite to the United States with a point-of-origin value of $48 per tonne, $10 cheaper than the Mexican price of $58 per tonne. Unfortunately, without knowing relative freight costs at the time one cannot calculate the price differential to the buyer.

Recent delivered prices for celestite that we have gathered from the U.S. consumer are close to $140 per tonne. We believe that this reflects a tightening of the market, with CPC increasing its buying price last year to guarantee feed at its expanded faculty.

Industrial Minerals Magazine quoted celestite at the Yate works at the equivalent of $110 per tonne in May 1985. With freight to the European consumer added, this would put its value at the buyer's plant at close to the U. S. figure.

The historic relationship between celestite and strontium carbonate prices seems to vary between 3:1 and 4:1. Strontium carbonate prices have been quoted to us by two major U.S. consumers as currently in the $660 to $720 per tonne (30-33 cents per pound) range. This conforms with prices quoted in the *Chemical Marketing Reporter*. Occasional shipments to consumers under quota restrictions from CPC have commanded higher payments. For example, Colt Industries purchased some carbonate from China for $1,250 per tonne last year.

FIGURE 2
U.S. AVERAGE VALUES FOR IMPORTED CELESTITE
(Based on Constant 1983 U.S. Dollars)

CURRENT CELESTITE PRODUCTION

While at least thirteen countries (including the U.S.S.R. and China) produce celestite, approximately 90% of current world production comes from just four -- Mexico, Spain, England, and Turkey.

Mexico and Spain are the largest celestite producers, and most of their output goes to the United States and Japan respectively. These two countries are the largest current consumers and, with no domestic production, rely totally on imports.

TABLE 5

1983 Celestite Production and Reserves (by Country)

	Mexico	Spain	Turkey	U.K.	Iran	Pakistan
1983 Production (000 tonnes)	30	35	15	18	5	0.3
Typical Grade of $SrSO_4$	92%	93%	97%	85%	91.5%	97%
Reserves (000 tonnes)	800	650	500	300	2,000	500
Capacity (000 tonnes/yr)	35-40	35-40	40	20	15	NA
Approx. Distance to pt. of Export	400 km	80 km	300 km (to Med. Sea)	20 km	200 km	600 km to near. Seaport
Primary Market	U.S.	Japan West Germany France	West Germany U.S.S.R.	Domestic	U.S.S.R.	Europe

Source: Various

Following is a description of current production by country.

Mexico

Mexico's primary celestite mine is in San Augustin in northern Mexico and is operated by Compania Minera La Valenciana SA of Torreon. Current reserves are 750,000 tonnes grading 92% $SrSO_4$. The other Mexican producer is located near Torreon and is operated by Compania Minera Ocampa SA. This operation contributes only a small portion of the country's total production.

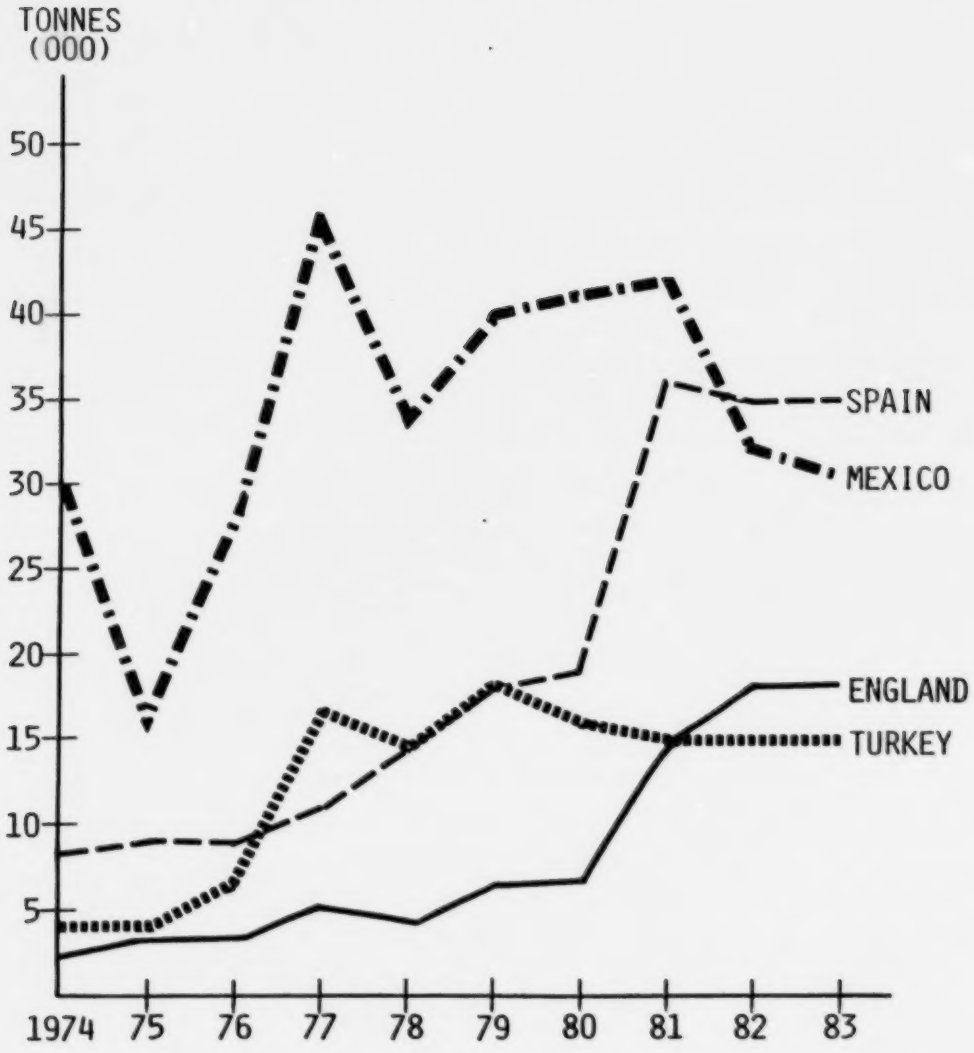
Celestite in the San Augustin deposit occurs in lens-shaped bodies concordant with the bedding of the Cretaceous limestone host rock. The orebody has a strike length of ten kilometers with an average thickness of five meters. The San Augustin deposit is unique in that it is mined underground (by the room and pillar method). All other current celestite producers use surface mining operations.

With ample high-grade reserves, inexpensive labour, and close proximity to the United States, Mexico's position as a major world supplier of celestite seems quite solid. (Mexico will also enter the strontium compounds market later this year, when La Valenciana starts producing strontium carbonate at a new plant in Torreon.)

Spain

The current producer in Spain is the Montevive mine, a few kilometers southwest of Granada in southern Spain, operated by Bruno SA of Madrid. Bruno's production capacity is 35-40,000 tonnes per year; in 1983 it produced 35,000 tonnes. Mineralization occurs within a flat-lying sedimentary formation associated with limestone, clays and gypsum. Spain has recently surpassed Mexico in annual production, mostly as a result of becoming Japan's primary supplier.

FIGURE 3
RECENT CELESTITE PRODUCTION OF FOUR LEADING PRODUCERS



Current reserves are 650,000 tonnes grading 93% $SrSO_4$. (Some less documented sources cite two million tonnes of proven and six million tonnes of probable ore.)

Selective mining of higher-grade celestite is done in benches of up to 0.5 meters in thickness in baritic gypsum-bearing host rocks.

The mine is eighty kilometers from the port at Motril. Spain's major consumer, Japan, takes about two-thirds of its output. The remainder of Spanish production is sold to West Germany and France, with occasional minor shipments to the United States.

Turkey

Turkey's two producing celestite mines are in the Sivas area, in the north-central part of the country. The larger mine is operated by Barit Maden Turk of Istanbul and the smaller one by Bilfer Maden Ltd. Sirketi, both of Ankara. Together the mines have an installed capacity of 40,000 tonnes of celestite per year, although in 1983 combined production was reported to be only 15,000 tonnes.

Proven combined reserves are believed to be about 500,000 tonnes grading 97%, although some sources have reported reserves as high as four million tonnes.

The Turkish deposits are quite distant from the nearest shipping port. The major current market for Turkish production is West Germany. Japan was a major customer until 1977, when it switched to Spain as its sole supplier.

A recent U.S. State Department report, which provides no other details, indicates that Turkey produced 35,000 tonnes in 1984. The additional 20,000 tons may have gone to help support the expansion at the Kali-Chemie strontium compound plant in Germany, and to Japan, which is once again a customer.

England

Current production in England comes from the Yate deposit, operated by Bristol Mineral Co. There are unconfirmed reports that the Minworth group also currently produces celestite in England. Capacity at Yate is about 20,000 tonnes per year, and 1983 production totaled 18,000 tonnes. Most of England's known reserves have been depleted during its long history of production (since the 1880s). Current reserves of 300,000 tonnes, averaging 85% $SrSO_4$, include 100,000 tonnes at the location of current mining operations in the Yate-Cromhall area. The remainder is located in the Wapley Bitton area, which has not been explored in much depth.

In the Bristol operation, celestite occurs at a depth of five to ten meters. Overburden is removed by bulldozers, after which a simple operation of washing and grading concentrates material to 95% $SrSO_4$. Periods of heavy rain limit production to nine months per year.

England's celestite production is consumed domestically.

Iran

A large deposit, operated by the Iran Strontium Company of Teheran, is located at Nakhjir, 200 kilometers southeast of Teheran. Capacity is believed to be about 15,000 tonnes per year, with 5,000 tonnes produced in 1983. Reserves are estimated at two million tonnes averaging 91.5% $SrSO_4$. About 500,000 tonnes are found right on the surface.

The celestite occurs in a seam with a strike length of about four kilometers and an average thickness of 2.5 meters. Mining is done by drilling and blasting along the crest of the hills. Although the grade of $SrSO_4$ is reasonably high at

91.5%, the Iranian ore has some competitive disadvantages, due to high levels of barite (1.75%) and calcite (3.3%) impurities.

This mine operates year-round and its current production is mainly shipped to the U.S.S.R.. Iran was previously a supplier to Japan but political strife resulted in its loss of that market in 1977.

Other Countries

Algeria

Algeria's celestite mine, operated by Sonarem, began production in 1971. Production in 1983 was about 3,000 tonnes.

Sonarem is believed to export its product to France.

Italy

Italian production comes from deposits at Gingenti, Caltarissetta, Favara, and Hiata, in the interior of Sicily. Production in 1983 was about 3,000 tonnes. Difficulty with high costs of production and transportation renders the feasibility of large-scale operations highly unlikely.

Italy is believed to consume its production of celestite domestically.

Argentina

Production in Argentina is carried out by the Argentine Mining Union. Output in 1983 was 800 tonnes.

There is no information available as to the reserves, grades, and types of operation of Algeria, Italy, and Argentina.

Pakistan

Celestite deposits occur at Daudkhel in the Mianwali District of the Punjab and are mined by Industrial Minerals Enterprises of Rawalpindi. The deposits have consistently produced less than 1,000 tonnes per year, with the exception of

6,000 tonnes in 1974. Nevertheless, Pakistan's reserve of 500,000 tonnes grading 97% $SrSO_4$ are comparable with the major producers.

Pakistan's output is sold to Europe. The long distance to the nearest seaport could present a major obstacle to the economic expansion of production.

China

China has two celestite deposits. According to a U.S. market source, one mine is currently in production in Southern China, with a grade of 82% $SrSO_4$. Its output is mostly consumed domestically, with some export to Japan and South Korea.

The other deposit is in the north, near Manchuria, and has a grade of 96% to 97% $SrSO_4$. This higher grade deposit is a long way from the strontium carbonate mill and because of high transportation costs due to the antiquated railway system, it is not yet producing. However, its proximity to Japan may make it a logical source of supply for that country in the future.

Cyprus, Poland, and Madagascar have recently been reported to be mining small amounts of celestite, but no detailed information is available.

CURRENT CELESTITE CONSUMPTION AND THE STRONTIUM COMPOUNDS MARKET

As the great majority of celestite is consumed in strontium compound manufacture, a review of current compound production also effectively describes celestite consumption. (For a brief description of direct uses of celestite, see page 3.)

Strontium compound consumption is quite difficult to analyze since consumers represent a very large, diverse group. (There are close to 1,000 small producers of strontium compounds in the United States and Europe alone.) Accurate statistics could only be developed by a more extensive survey than this. Therefore, for our purposes, in the following sections we have chosen to review the strontium compound market by country.

Three countries -- Japan, the United States, and West Germany -- produce most of the world's strontium compounds. England, Spain, France, and Turkey produce minor amounts. China is a growing new producer. The U.S.S.R. is also believed to produce strontium compounds for its own use from a combination of domestic and imported celestite but no figures are available.

Of the three larger strontium compound producers, West Germany is the only major exporter, whereas Japan and the United States, the largest compound consuming countries, must at times import compounds to meet domestic production shortfalls. None of these countries has domestic celestite production, and therefore they rely totally on imported celestite to feed their compound manufacturing plants.

Mexico is planning to enter the strontium compound market by the end of this year. Its anticipated initial production of 10,000 tonnes per year could have a significant effect on the world market.

Following is a more detailed look at compound production by country:

United States

The United States is a leading producer and consumer of strontium compounds, consuming over 20,000 tonnes of contained strontium yearly. The main producer and only carbonate manufacturer is Chemical Products Corporation (CPC) of Cartersville, Georgia, which has recently expanded production by about 30% from previous levels of approximately 9,000 tonnes per year of strontium carbonate. CPC is in the process of gearing up for the production of strontium nitrate with equipment purchased from the recently closed FMC plant (producing about 9,000 tonnes per year) at Modesto, California. Other, smaller U.S. companies produce a variety of strontium compounds, mostly from carbonate purchased from CPC.

For the past year, CPC has had to put quotas on its sales because of inability to meet consumer demand. Kali-Chemie of West Germany has met the extra demand with imports.

TABLE 6

Current Major U.S. Producers of Strontium Compounds

Company	Location	Compounds
Barium and Chemicals Inc.	Steubenville, OH	Various
Chemical Products Corp.	Cartersville, GA	Carbonate
Mallinckrodt Inc.	St. Louis, MO	Various
Mineral Pigments Corp.	Beltsville, MD	Chromate
Wayne Chemicals	Milwaukee, WI	Chromate

Source: U.S. Bureau of Mines

Wayne Chemicals used 900,000 pounds of carbonate and one million pounds of nitrate in 1984. Contrary to standard practice, Wayne Chemicals is currently using only carbonate in its production of strontium chromate, due to unavailability of strontium nitrate following the FMC closure.

Mallinckrodt produces small amounts of compounds for the pharmaceutical industry. Barium and Chemicals is a minor producer and claims to be working off a stockpile of celestite purchased several years ago. Chemical Pigments is also believed to be a minor factor.

The Milwhite Company of Houston, Texas, not mentioned in the above table, imports Mexican celestite and manufactures a processed celestite product.

TABLE 7

U. S. Strontium Compounds Demand
1969 - 1983
(Short Tons of Contained Strontium)*

	1969	1970	1971	1972	1973	1974	1975	1976
Television picture tube glass	8,400	9,500	9,600	7,000	8,000	9,500	6,400	11,000
Pyrotechnic materials	3,500	4,600	5,000	3,200	2,400	4,400	3,000	4,000
Ferrite magnets	1,500	2,500	2,700	2,000	2,600	2,800	1,900	1,500
Ceramics and glass	550	650	650	650	700	800	900	100
Electrolytic production of zinc	600	600	600	600	600	800	900	1,200
Pigments	75	75	75	75	100	160	100	200
Other	1,200	1,200	1,235	1,220	1,900	1,340	700	1,700
Total demand (celestite and compounds)	**15,825**	**19,125**	**19,860**	**14,745**	**16,300**	**19,800**	**13,400**	**19,700**

(Table 7 continued on next page)

	1977	1978	1979	1980	1981	1982	1983
Television picture tube glass	12,300	13,700	14,000	13,300	12,400	10,300	14,500
Pyrotechnic materials	3,000	3,600	3,600	2,400	2,800	2,600	3,200
Ferrite magnets	900	1,000	1,100	1,000	1,000	1,200	1,100
Ceramics and glass	200	250	300	100	100	100	200
Electrolytic production of zinc	1,300	1,500	2,000	1,000	800	500	900
Pigments	220	250	200	800	800	700	700
Other	1,060	600	900	1,300	1,300	1,300	2,100
Total demand (celestite and compounds)	**19,000**	**20,000**	**22,100**	**19,900**	**19,200**	**16,700**	**22,700**

*To convert to metric tonnes multiply by 0.905
To convert to rough celestite equivalent (assuming grade of 92% $SrSO_4$) and recoveries of 90%, multiply by 2.75

Source: U.S. Bureau of Mines

As can be seen from the above chart, the most significant growth in U.S. compound consumption from 1969 to 1983 was in the areas of colour television picture-tube glass and pigments.

Among the major consumers of strontium compounds for direct manufacturing purposes are Owens Illinois, which consumes 7-9,000 tonnes per year; RCA, which consumes about 5,500 tonnes per year; and Corning Glass, all of which use carbonate in television tube manufacture. Hoosier Magnetics and Colt Industries are the main consumers for ferrite magnet manufacture, and Olin for pyrotechnics.

In recent years, production of strontium compounds in the United States has been unable to keep pace with demand. The loss of FMC's production in 1984 has been mostly met by expansion of capacity at CPC. Nevertheless, CPC has had its customers on quotas for the past year and the United States is continuing to rely on imports. The following table details imports in 1982 and 1983, while the succeeding table gives overall import data to 1984 for the United States and Japan.

TABLE 8

U.S. Imports of Strontium Compounds (by Country)

	1982		1983	
	lbs	Value in $	lbs	Value in $
Strontium carbonate:				
West Germany	2,867,842	$797,820	977,690	$301,667
England	46	3,609	5,181	11,771
Netherlands	3,120	3,010	--	--
Total	2,867,842	804,439	982,871	313,438
Strontium chromate:				
Canada	462,815	634,893	53,010	59,131
France	27,006	27,714	235,284	240,994
West Germany	14,318	10,427	3,337	5,588
Poland	35,274	21,199	--	--
Spain	--	--	28,660	31,034
England	228	2,073	10,155	10,788
Total	539,641	696,306	330,446	347,535
Strontium nitrate:				
West Germany	1,228	5,774	--	--
Italy	363,200	136,160	815,414	351,230
Spain	41,887	14,007	45,194	15,622
England	13	874	--	--
Total	406,328	156,815	860,608	366,852
Other Strontium compounds:				
France	4,000	5,040	--	--
West Germany	8,973	16,523	18,963	21,132
Japan	44,092	32,693	24,246	13,698
Netherlands	--	--	366	4,453
Spain	--	--	39,683	14,028
England	771	1,273	16,983	21,411
Total	57,836	55,529	100,241	74,722
Strontium metal:				
Canada	14,633	137,070	1,991	22,790
Grand total	**3,886,280**	**1,849,619**	**2,276,157**	**1,125,337**

Source: U.S. Bureau of the Census

TABLE 9

Celestite Imports United States and Japan
(000 tonnes)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Japan	12.0	16.5	24.0	20.0	30.0	35.0	N/A	N/A	N/A	N/A
U.S.	14.5	32.5	38.5	37.5	40.0	35.0	43.5	30.0	42.6	44.3

Source: Various

Japan

The three major Japanese producers of strontium compounds are Honjo Chemicals, Sakai Chemical Industry (where capacity was reported several years ago at 8,600 tonnes per year of strontium carbonate), and Nippon Tokushu Kasei.

In 1982, the latest date for which confirmed figures are available, Japan consumed 32,000 tonnes of strontium carbonate. Celestite is imported mostly from Spain, with small amounts from Turkey.

Japan's domestic compound production has been unable to keep pace with demand, and the country regularly imports strontium compounds from Kali-Chemie in West Germany (7000 tonnes in 1980). The government has planned to stockpile 5,000 tonnes in the hope of meeting potential future shortfall.

TABLE 10

Japanese Consumption of Strontium Compounds by End Use in Japan 1977 -- 1982 (000 tonnes strontium carbonate equivalent)*

	1977	1978	1979	1980	1981	1982
Colour T.V. tubes	12.5	13.0	15.0	20.0	19.0	22.5
Ferrite Magnets	4.5	6.5	9.0	11.0	4.2	5.5
Pyrotechnics	0.6	0.6	0.6	0.6	NA	NA
Other	0.8	0.8	1.0	1.0	NA	NA
Total:	18.4	20.9	25.6	32.6	NA	NA

*To convert to strontium equivalent, multiply by 0.59

Source: Various

Japanese consumption increased greatly in the late 1970s. In 1977, Japan consumed 12,500 tonnes of strontium carbonate in the manufacture of colour television picture tubes, but by 1980 it had increased consumption to 20,000 tonnes. In 1975, Japan used only 1,500 tonnes in ferrite magnet production, but by 1980 that figure had reached 11,000 tonnes. The sharp rise in figures reflected not only an increase in the production of magnets but a significantly higher use of strontium carbonate as a replacement for barium in that use.

In 1981, however, the country used only 4,200 tonnes of strontium carbonate in the production of ferrite magnets, and only 5,500 tonnes in 1982. These figures reflect a renewed use of barium rather than strontium compounds. However, due to the comparatively poor performance and reliability barium displays in this use, in the past two years strontium carbonate consumption in ferrite magnets reportedly has recently returned to its high level of 1979 and 1980.

West Germany

Kali-Chemie AG, located in Hanover, West Germany is the main producer of strontium compounds in Europe and the world's largest exporter. Kali-Chemie

produces a number of different grades of strontium compounds that are sold throughout Europe as well as to North America and Japan.

Kali-Chemie, a substantial chemical company, is also a major supplier of barium compounds. The company increased capacity and production of strontium by one-third last year to meet what it sees as growing worldwide demand.

Kali-Chemie has accounted for the great majority of U.S. imports of strontium carbonate since the closing of Kaiser's plant in 1976. An Italian subsidiary, SABED, produces strontium nitrate, and accounts for most of the U.S. imports of that compound.

Spain

Promociones Industriales del Sur SA (Proinsur), a division of Bruno, Spain's celestite miner, produces a low "technical grade" of strontium carbonate which is mainly used in zinc production. Design capacity is about 8,000 tonnes yearly. Proinsur also produced strontium nitrate, but stopped because of lack of markets for its material.

Italy

Italy has two strontium nitrate producers. The Societa Bario e Darivati SpA (SABED) a subsidiary of Kali-Chemie, and Ammi Bario. The strontium nitrate is both exported and consumed domestically.

Mexico

Compania Minera La Valenciana is beginning strontium carbonate production later this year at Torreon. Initial production is slated at 10,000 tonnes

per year of carbonate, with the installed potential to expand to 18,000 tonnes per year.

Canada

There are no domestic producers of celestite or strontium compounds at present, and the Canadian market for strontium compounds is very small. Mitsubishi, in Ontario, is currently the only Canadian colour television picture-tube producer but it imports its face glass. The extent of ferrite magnet manufacture is hard to determine, but is believed to be extremely limited. A handful of pyrotechnic companies, such as Hands Fireworks, in Quebec, use several tons of carbonate and nitrate yearly.

The largest Canadian consumer is believed to be the Chromasco division of Timminco, which consumes several hundred tonnes of carbonate yearly to produce strontium metal. The Chromasco plant, located at Haley, Ontario, also produces calcium and magnesium specialty products.

Unfortunately, Canadian federal government figures are not of much help in developing overall statistics. The only import figures they show for 1984 are for a few tonnes of strontium hydroxide and peroxide imported last December.

Other Countries

Other countries known to produce strontium compounds, such as France, Turkey, and England, manufacture small quantities largely for local markets. The U.S.S.R. and East Germany are believed to have recently increased their consumption of strontium carbonate as a replacement for barium compounds.

RECENT CHANGES IN SUPPLY

New Production

A recent U.S. census report indicates that Madagascar has a new producing celestite mine. No information is yet available on the grade of celestite, the amount of reserves, or the current market.

Mexico is believed to have several new sources of celestite coming into production to service the U.S. market. Exact figures are not available. There are currently a number of small hand-sorting operations in Mexico that have arisen in response to the strong U.S. demand.

La Valenciana plans to enter into the compounds market with production of strontium carbonate by the end of 1985. The plant, located in Torreon, is reported to have an initial capacity of 10,000 tonnes per year with the installed potential to expand to 18,000 tonnes yearly. Equipment was purchased from the closed FMC plant in the United States. Some industry sources believe Mexico will have the capability to produce as much as 30,000 tonnes of carbonate yearly.

According to published reports, La Valenciana encountered initial quality problems with magnesium content in its pilot production and has hired some former FMC employees to help overcome them. However, a knowledgeable U.S. market source told us that its basic difficulties were financial and that the magnesium issue was incidental. The most likely market for this production will be the United States, which will put the Mexican producers in competition with CPC.

In the U.S.S.R., mining of celestite ore has begun in Southeastern Turkmenia. An experimental plant for the processing of strontium compounds has gone into service at the Gaurdak sulphur works.

Closures

In 1984, FMC closed its plant in Modesto, California. FMC was producing strontium as well as barium compounds mainly for the U.S. market, and its closure left CPC as the only major U.S. strontium compounds producer. According to the ex-plant manager, FMC's decision to close its plant was based on continuing losses from high costs incurred as a result of California wage rates and environmental laws, and freight disadvantages to the market incurred from its west coast location. In addition it had lost sales to Kali-Chemie, which had made a concentrated effort to capture U.S. market share in the early 1980s.

Barium and Chemicals Corporation of Steubenville, Ohio plans to cease production of strontium carbonate in the near future. The company president says the company has only produced minor amounts of carbonate from a stock of celestite purchased a number of years ago, and that it is more active in the manufacture of other chemicals.

Expansions

Chemical Products Corporation expanded its operation during the past year in an attempt to make up the shortfall caused by the closure of the FMC plant. The expansion did not involve much capital investment but entailed increasing shifts, and emphasized efficiency and increased productivity. However, CPC has been unable to meet the entire U.S. demand. As a result, there has been a shortage

of strontium compounds in the United States since last summer. CPC could be interested in further expansions if it had a solid source of raw material.

CPC is now producing strontium nitrate as well as carbonate. The company bought some of FMC's equipment and stock of nitrate and hired some of the former FMC staff.

Kali-Chemie of West Germany expanded its plant by one third to continue its attempt to expand sales and meet the shortfall in the United States caused by the closure of FMC.

In Turkey, Barit Maden Turk is in the midst of expanding its celestite capacity in Sivas from 20,000 to 40,000 tonnes per year. Turkey is unofficially reported to have produced 35,000 tonnes in 1984.

ANTICIPATED MARKET DEVELOPMENTS

U.S. Bureau of Mines forecasts for consumption growth are shown in Tables 11 and 12 on page 39. These numbers are based on forecast growth rates for the consuming industries, although the government reports that only in the case of picture tubes does past data show a close correlation to exist.

The Outlook for Strontium Compounds Consumption

The color television picture-tube market, which consumes the bulk of strontium production, is likely to experience good growth in the United States.

The United States currently has legislation in place requiring the use of strontium to block harmful x-rays from the television tube, but European and developing countries have no such requirements, and they mainly use barium in tube manufacture. (A change could be brought about by consumer health activists, but no one we talked to in the marketplace currently considers this likely.)

The U.S. government "probable" forecast reflects its view of the maturity of the market. The "low" forecast reflects the possibility of colour television declining in popularity due to competition from new technologies, such as large projection screens, in the home entertainment field. Our own feeling is that this possibility is overrated as are most "straight line" extrapolations of the future.

Although in recent years the United States has lost a share of the new picture-tube market to Japan, the manufacture of replacement tubes is helping to maintain growth. Two major U.S. manufacturers of colour television picture tubes (RCA and Owens Illinois) expect the growth in tube demand to be substantially

more than the modest amount expected in a "mature" market. RCA, which currently consumes 6,000 tonnes of strontium carbonate yearly, expects the U.S. market to grow more than 10% per year based on current strong activity in the colour television market. Owens Illinois, which currently consumes 8 to 10,000 tonnes of strontium carbonate yearly, is planning a plant expansion to increase its production by 50%. Nevertheless, Japanese competition is a significant factor and could conceivably undermine these optimistic outlooks.

RCA is also in the experimental stage of developing colour monitor sets for home computers. These will require the same strontium carbonate content as television tubes. RCA feels that if color monitors catch on with the public, the current U.S. demand for strontium carbonate could double by 1988.

As in many metal and mineral markets, China looms as a potentially significant factor. China expects to produce 500,000 colour television picture tubes in 1985 and 10 million per year by 1988. (U.S. production was slightly over 11 million in 1984.) The Chinese are currently building a number of colour television picture-tube plants that are expected to be in production by the end of this year. China's capacity to meet its internal demand projection is unknown, but it is safe to assume that reserves are available.

Ceramic ferrite magnets production is the next largest consumer of strontium compounds worldwide after television tubes. (In the United States this use is less than that for pyrotechnics.) This market is currently quite strong in Japan, and has experienced a recent strong increase in the United States due to strontium's demonstrated higher efficiency and cost effectiveness over barium carbonate.

Two leading manufacturers of ceramic ferrite magnets in the United States (Hoosier Magnetics and Crucible) indicated to us that an annual growth of at least

10% per annum is likely in the relatively small U.S. market over the next few years. The U.S. Bureau of Mines forecast is substantially more modest and anticipates continued competition from barium in this usage.

The U.S. Bureau of Mines deems no growth likely in the use of strontium nitrate in **pyrotechnics**. In fact, it believes that a slight decline in use may result due to the anticipated replacement of railway flares by battery operated signal lights. (It is worth noting, however, that the use of fireworks in the United States has increased by 90% in the past decade.)

The high forecast of 4,000 tons in the year 2000 anticipates possible increased usage in special effects, such as simulated explosions for movies and television.

Little change is predicted in the growth trend of the other strontium compounds, with the possible exception of strontium chromate, which is used in **industrial and marine paints**. Concern about the toxicity of lead and zinc in pigments has increased substitution potential for strontium chromate in low-toxicity pigments.

As the other compounds make up only 5% of the total world consumption, even substantial growth would only have a small impact on overall celestite demand.

TABLE 11

Forecasts for U.S. Strontium Compounds Demand by End Use 1983 and 2000
(short tons of contained strontium)

		Year 2000			
	1983	Projected*	Low	High	Probable
television Tube Glass	14,500	28,500	15,000	28,500	20,000
Pyrotechnic	3,200	4,300*	3,000	4,000	3,500
Ferrite Magnets	1,100	0*	1,000	2,500	2,000
Elec. Prod. Zinc	900	2,100*	1,000	1,500	1,200
Pigments	700	1,200*	700	1,400	1,200
Ceramics & Glass	200	0*	200	500	300
Other	2,100	1,900*	1,500	2,500	1,900
Total	23,000	---	22,000	41,000	30,000

* Statistical projections based on GNP and PRB indices and historical time series.

Source: U.S. Bureau of Mines

TABLE 12

Forecasts for Worldwide Strontium Compounds Demand
1990 and 2000
(thousand short tons of contained strontium)

		2000 Forecast Range		Probable		Probable Annual Growth Rate
	1983	Low	High	1990	2000	1983-2000
United States						
Total	23	22	41	26	30	1.6%
Cumulative	--	380	540	170	450	--
Rest-of-World						
Total	36	46	68	42	53	2.3%
Cumulative	--	700	870	280	760	--
World						
Total	59	68	109	68	83	2.0%
Cumulative	--	1,080	1,410	450	1,200	--

* To convert to metric tonnes, multiply by 0.905.

Source: U.S. Bureau of Mines

TABLE 13

Adequacy of World Strontium Reserves
(thousand short tons of contained strontium)

	U.S.	Rest-of-World	Total
Reserves	--	7,500	7,500
Cumulative Primary Demand 1983-2000	450	760	1,200

Source: U.S. Bureau of Mines

Further growth in consumption beyond that already discussed would require the discovery of new uses for celestite and the strontium compounds. Strontium is one of the less-researched and understood elements of the periodic table, and appears to have potential applications in the manufacture of aluminum, silicon and other light metals and structural clay products, and in solid electrolyte in fuel cells.

Potential Competition

In examining future prospects for strontium, it is necessary to consider competition from barium. Barium is similar in chemical nature to strontium and has been substantially cheaper. This has contributed to the fact that barium production worldwide is some twenty times that of strontium. However, strontium has been making inroads into barium usage on several fronts in the past decade. (The financial implications for individual producers is complicated in an interesting fashion by the fact that a number of strontium compound producers have the ability to switch to barium compounds, and vice versa.)

Barium could replace strontium in the colour television picture-tube markets in the United States and Japan only after extensive redesign of circuitry to reduce operating voltages that produce harmful x-rays.

In ferrite magnet production, replacement by barium would decrease the energy and temperature range of the magnet. In fact, the discovery of the superior performance of strontium, which has a higher resistance to demagnetization, has resulted in both the United States and Japan recently increasing strontium carbonate use in the production of ferrite magnets.

There also seems to be little likelihood of substitution in the pyrotechnics market. Although calcium and lithium impart red color to a flame, the needed brilliance and visibility can only be imparted by strontium nitrate in combination with other strontium compounds.

In ceramics production, however, although strontium compounds are effective, they may still be replaced by zinc, magnesium, barium, or calcium oxides.

In sum, strontium may theoretically be substituted for in virtually all its uses save perhaps pyrotechnics. Nevertheless, manufacturers who have done so frequently have found that they have sacrificed efficiency and performance, and many of these have returned to strontium usage.

Future advances in technology may mean that smaller amounts of strontium will be required in some of its applications. Nevertheless, it is equally possible that significant new uses may be found for strontium compounds.

IMPLICATIONS FOR THE FEASIBILITY OF THE ENON DEPOSIT

The following section summarizes some of our broad observations on the implications of current market structure and trends for the development of a celestite or strontium compounds producer at Enon.

With plant site values in some cases close to $100 per tonne, it is believed that most current celestite operations are profitable. Open-pit mining, without the need for milling, is the cheapest form of mineral production and could cost as little as $10 to $20 per tonne at some operations. Transportation to the buyer will thus obviously be the determining factor in celestite mine feasibility.

The Relative Standing of Enon

The Enon celestite deposit in Cape Breton, Nova Scotia, is among the largest in the world, with measured and indicated reserves of close to two million tonnes. However, the grade of $SrSO_4$, ranging from 50% to 60%, is lower than that of any current celestite producer. All these producers operate deposits with grades of more than 90%, with the exception of the Yate deposit in England, where starting grade is 85% and the celestite is washed and gravity-separated to yield a product containing 95%. When Kaiser operated the Enon deposit, celestite ore was first beneficiated to yield a grade of 88% to 92%, before being processed into strontium chemicals.

Kaiser encountered certain problems in mining the celestite ore at the Enon deposit. The ore zone is dislocated by faulting, and there is irregular distribution of the mineral, brecciation of the host rock, and radical stratigraphic variation. In

any future production, these problems could result in a high dilution of the already low-grade celestite, unless a potentially costly program of detailed drilling were performed to precisely outline the higher grades of material. According to one consumer who has tested the material, most of the celestite ore at Enon has a high calcite content (more than 0.5%), which is costly to remove.

Further large-scale development of the deposit will entail an underground operation, which will also add to costs when compared with open-pit mining.

All of the factors described above could contribute to placing the Enon deposit in the high-cost end of current production, most of which comes from developing countries with low labor costs and high-grade deposits.

Conclusions from the Kaiser Operation at Enon

Kaiser Celestite Mining Ltd., a subsidiary of Kaiser Aluminum and Chemical Canada Ltd., brought the Enon mine onstream late in 1969, in order to supply celestite as a feed for high-grade strontium compound production. The deposit had been discovered in 1962 and purchased by Kaiser in 1969. The concentrator plant started up early in 1971. Mine design capacity was 68,000 tonnes per year. Strontium carbonate production capacity at the compound plant was about 27,000 tonnes per year.

The operation was beset by technical problems from the beginning. There were virtually no recoveries of celestite for the first three months, and it took a year and a half to get recoveries into the 70% to 75% range. By 1973, the plant (which started with mostly used equipment) had been effectively redesigned, the work crews had gained substantial experience, and recoveries were in the mid-80 to low-90% range.

However, problems continued at the compound plant. By 1976, compound production problems had been sorted out and both plants were operating smoothly. But due to continuing losses and a poor market outlook Kaiser closed the operations in mid-1976. The two sites had a total of about 100 workers and a book value of $19 million. Kaiser attempted unsuccessfully to sell the facility, and then auctioned off its contents in 1978.

Just prior to closing, Kaiser had been investigating the viability of selling celestite rather than engaging in further processing. One of the plant managers at the time told us that the company determined that it could make celestite at a profit (the celestite price at port at that time was reported to be about $28 per tonne), although it was believed to be still incurring losses on its compounds operations.

The fact that a celestite mining and processing operation took place previously on and near the Enon property creates some favorable conditions for a new operation. Kaiser spent substantial amounts of money perfecting its process; most of the technical information would be available to a new operator through ex-Kaiser employees. Many of the skilled laborers and managers from the Kaiser operation still reside in Cape Breton and, according to one manager, would be interested in working for a new operator. In addition, Kaiser identified nearby celestite sources that could be considered in determining the most economic mining/processing scenario.

Evaluating The Project

In order to arrive at a notion of the value of the Enon deposit, it is necessary to ascertain an optimal size of operation, likely sales prices for the material, and the costs of delivering it to market. Various discounted cash-flow

criteria can then be applied to arrive at a net present value. This exercise is outside of the scope of the current study, but we feel we can provide some helpful guidelines, gleaned from our analysis, to help provincial planners with the assessment of bids. The following statements are directed towards celestite production, but most points apply to the feasibility of chemical production as well.

Estimating Future Prices. To estimate future prices with any degree of confidence would require a substantially larger study than this. However, there are a few observations that can be made.

1. The market for both celestite and strontium chemicals is currently tight and continuing reasonable growth in strontium chemical demand can be projected. Normally, this would lend confidence to using current sales prices as a basis for projections for the next several years.

2. However, current market conditions seem to be attracting a number of potential market entrants, including several new Mexican suppliers. This could result in a "price war" that would knock the profit out of the market for everybody.

3. Therefore, to predict the low end of future prices, it is necessary to have some idea of competitor's production and delivery costs, in order to see what levels of sales prices they could sustain without going out of business. Current competitors for a Nova Scotia production that would feed the U.S. market are Mexican; competitors for overseas markets would be largely third-world producers. As a rough rule of thumb, we would halve the current price of celestite to $70 per tonne to provide a conservative "bottom" for forecasts.

4. Nova Scotia's vulnerability on production cost could be to a small degree offset by its attractiveness as a stable country supplier. Much of the competitive economics would depend on the freight costs available. To sell to CPC, material could be trucked to Sydney and then shipped by part charter, or perhaps by barge, to Savannah, Georgia. From there it is an easy truck haul to CPC. The material from Torreon is railed for approximately 1,500 miles.

   Enon production would clearly have a freight advantage to Canadian producers such as Chromasco, but its volume of current consumption is too small to justify a major commercial operation.

   Freights might turn more to Nova Scotia's favor on compound production, where it would be competing with CPC, Mexico, and West Germany for northern U.S. markets.

5. We believe that there may be some possibility for a Nova Scotia producer to hedge the celestite market by taking advantage of the "security" that his presence could provide to the U.S. and Canadian consumer. A producer could potentially protect his first few years' income by selling a good part of his production on a fixed contract basis at a price acceptable to both himself (providing an adequate profit margin) and the consumer (at below the current market).

6. Strontium compound production could show certain advantages in minimizing the drawbacks of Nova Scotia's competitive position with regard to labor and freight costs. However, Mexico's entrance into that market (and its likely aggressive pricing policy based on its need for U.S. dollars) and Kali-Chemie's strong position do not render this an immediate attractive possibility.

Other Considerations. Timing of new production is an important consideration. At the moment, there seems to be a "window" in the market, which is not likely to last more than another year or so. After that, it will be more difficult for a new producer to enter the market.

The size of projected new output is obviously a critical factor. One of the problems of the Kaiser operation at Enon was that it was too large for a new market entrant. Customers will be cautious about dedicating anything more than a small percentage of their supply needs to a new producer, although, as stated before, many will be hoping to find a major source in Enon if it proves quality- and cost-competitive. As a rough idea we would estimate that a start-up capacity size of 10,000 tonnes per year, with a possible increase to 20,000 tonnes per year, could be in the realm of consideration based on the U.S. market. The European market (primarily Kali-Chemie) could be accessible at reasonable freight rates but would be harder to break into.

As CPC is the only U.S. celestite consumer, it could make sense to speak to them directly. (In our conversations with them they expressed a definite interest in the Enon deposit. We did not mention our connection with the project, but they discussed it, and revealed a reluctance to engage in operations in another country, which we feel could be greatly counteracted by government incentives.) Any other developer of celestite production would most likely be trying to sell to CPC or running a very small operation.

Nova Scotia's high-production-cost position could be favorably influenced by the incentives that are, or could become, available for Cape Breton enterprises. The potential availability of the ex-Kaiser mill at low cost would also favorably influence project economics.

In evaluating chemical production in particular, another wrinkle is introduced by the fact that some companies may be developing new or more efficient processes for proceeding directly from the Enon ore to a strontium product. It is impossible to assess the economic impact of such new processes, but they could result in rendering a company's internal economic assessment of the project substantially different from that of an outside observer.

The proximity of the Enon deposit to the United States, the largest major consumer, gives it an advantage over all the current celestite producers with the exception of Mexico. However, Canada definitely enjoys an advantage over Mexico as a supplier in the eyes of consumers of both celestite and strontium compounds, because it is viewed as a more stable and reliable trading partner. Its entrance into the market would also provide a welcome alternative to further dependence on one source.

Additionally, all the major U.S. consumers of strontium compounds are already looking for new sources of supply, due to CPC's inability to meet domestic demand. U.S. colour television picture-tube manufacturers are currently concerned with competition from Japan and would like to see more availability of strontium carbonate in the United States to stabilize the price and allow them to increase production. Some imports have come from Kali-Chemie, which according to several consumers is price-competitive (although they would have a vested interest in telling us that), while others say it has taken advantage of U.S. shortages by charging premiums.

Smaller manufacturers, such as chromate producers, find that relying on an offshore producer, such as Kali-Chemie, for part of its carbonate supply involves problems with uncertain availability and delivery and is thus not desirable. Mexico is believed to be readying a major entry into the U.S. compound market

but, as mentioned above, U.S. consumers do not want to rely on supply from that source.

Both the U.S. compound consumers and CPC itself are unhappy with the latter's dependence solely on Mexican celestite supply. In a similar fashion, much of the European and Japanese market is supplied with celestite from developing countries that might be regarded as less than stable. With celestite production operating at close to capacity worldwide, this would create a good rationale for European or Japanese interest in the Enon deposit.

Thus the entrance of a Canadian celestite and/or compound producer into the world, and especially into the U.S. markets, might be very favorably received. This has not gone unnoticed; our contact at RCA reported that "seven or eight" companies had approached him to discuss potential new sources of strontium carbonate. A number of these could have the Enon deposit in mind. However, at least two of these groups mentioned the possibility of importing celestite from a cheap overseas source and upgrading it to strontium compounds at sites in the United States. There is no shortage of known celestite deposits and several might be attractive candidates. Barium producers, who could easily convert their existing mills as well as benefit from diversifying into a strong competitor, would be good candidates for this.

It is worth mentioning that there may be potential domestic markets or added processing possibilities for a Nova Scotia celestite or strontium compound production. Two uses described in the study are pyrotechnics and marine paints. Both may be of local interest, given Nova Scotia's marine industries and naval activities.

Some Marketing Issues

Even if the economics of a celestite or compounds production look favorable on paper, a strong and well-informed marketing effort would be necessary to make the project a success. This is a common theme in most new "industrial minerals" operations, and often presents pitfalls for new producers (such as Kaiser).

Different customers will have varying requirements for the characteristics of their feed. Some compound producers will accept more barium in celestite than others. Generally speaking, ferrite magnet producers will need a finer and higher grade of strontium carbonate than picture-tube producers. But the most frequently repeated marketing theme that we heard from the celestite consumers was their need for a consistent quality of feed.

We received some conflicting information on what the impurities problems were in celestite, but the most important point seemed to be that buyers of both celestite and compounds could adjust to a known level of impurities as long as it remained consistent. The fact that it takes time to establish consistency and get the confidence of the buyer, thereby being in a position to supply a larger share of a customer's needs, must be taken into account in projections of early sales volumes. Thus, with celestite, as with other performance-critical industrial minerals, the final assessment of feasibility must rest on extensive contact and dialogue between producer and consumer.

Transportation is obviously a major consideration in strontium economics. CPC receives celestite as lump material delivered in rail cars. It could also receive trucks. Its main concern in shipping is to avoid the creation of fine powder, which gives it handling problems.

A quick look at existing freight rates from Sydney to the main U.S. celestite customer in Georgia is not encouraging. Special rail rates, barge rates, or part-charters would need to be negotiated. Strontium compounds, on the other hand, would be less freight-sensitive and would require shorter shipping distances, with much of the potential market in the northern United States. In addition, consumers would perceive an advantage in strontium compound shipped by rail or truck. These could be shipped in smaller amounts and on shorter notice than overseas shipments.

APPENDIX

The Manufacturing Process

There are two processes commonly used to produce strontium carbonate from celestite.

The **calcining** or **black ash process** or **dry process**: Strontium sulphide is reduced at high temperatures by using coal or coke to form a water-soluble sulphide, which is then settled and mixed with water. The insoluble impurities are filtered out and the resulting sulphide is treated with carbon dioxide to produce carbonate, or with the appropriate acids to produce other compounds.

This process yields high purity or "chemical-grade" strontium carbonate, suitable for use in the production of colour television picture tubes and ceramic ferrite magnets.

The **soda ash** or **metathesis process**: Finely ground celestite of 200 to 300 mesh is washed with either hydrochloric or sulphuric acid to convert a proportion of the impurities to soluble compounds. After washing and thickening, the celestite is then thoroughly mixed with soda ash and steam. The resulting strontium carbonate is separated from the sodium sulphate liquor and is further washed and thickened.

The metathesis process yields a lower purity or "technical grade" strontium carbonate that is suitable for use in the production of Special High-Grade brand zinc and as a basis for further processing into other strontium compounds.

In both these processes, the carbonate forms as a solid, which is flash-dried and screened.

The capital costs of the metathesis method are much lower than those of the black ash method, but it has the disadvantage that a number of impurities such as calcium, silica, and iron remain in the carbonate,

A third process was employed by Kaiser in Nova Scotia. The "Kaiser process" involves a combination of the other two processes. Strontium sulphate is directly converted to "technical grade" or lower-grade carbonate, which is then roasted in a high-temperature kiln (at 1,400^{o}C) to break it down into strontium oxide and carbon dioxide gas. The strontium oxide is quenched or leached with water to yield pure strontium hydroxide, which is then reacted with carbon dioxide gas to yield extremely pure strontium carbonate.

The Kaiser process is more sophisticated and more expensive than the other two methods. It was developed to deal with the low-grade and high-impurity content of the Nova Scotia ore.

Strontium metal is produced by thermal reduction of strontium oxide with metallic aluminum, and by electrolysis of fused strontium chloride and ammonium or potassium chloride.

Strontium nitrate is produced from strontium carbonate by adding nitric acid to the carbonate. The resultant liquor is decanted and filter-pressed to remove insolubles. Strontium nitrate crystals are then formed by vacuum crystallization.

Strontium chloride is produced in a similar fashion, with hydrochloric acid as the active agent.

Other strontium compounds are obtained by similar procedures consisting of converting the carbonates, sulphides, or hydroxides with the corresponding acid for each compound. The principal starting point for nearly all the other strontium

compounds is strontium carbonate. In this respect, material made by the metathesis process is competitive with the black ash product.